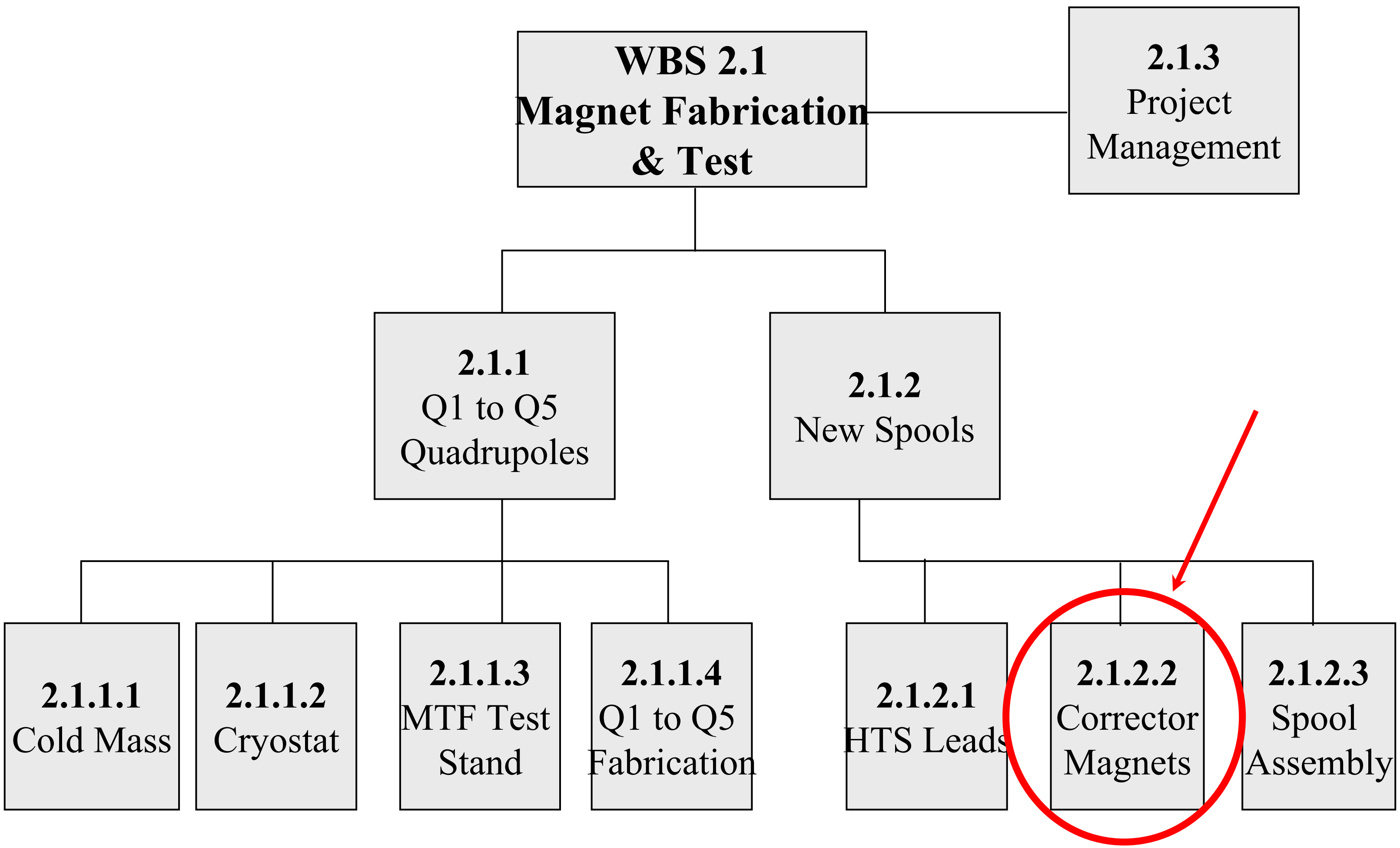
Corrector Magnets (WBS 2.1.2.2)

J. Tompkins

Corrector Magnets – WBS Overview

WBS 2.1.2.2

Where we are in the WBS structure:



- Correctors needed:

		Corrector Magnets					
Spool	**Slot Length, m**	**VD T. m**	**HD T. m**	**SQ T.m/m**	**Sx T.m/m2**	**Q* T.m/m**	**Total per Spool**
X1V	1.83	**0.48**	*(0.48)*		**450**	**25**	**3**
X1H	1.83	*(0.48)*	**0.48**		**450**	**25**	**3**
X2L	1.43	**0.48**	**0.48**				**2**
X2R	1.43	**0.48**	**0.48**				**2**
X3	1.43	**0.48**	**0.48**	**7.5**			**3**
X3	1.43	**0.48**	**0.48**	**7.5**			**3**
X2R	1.43	**0.48**	**0.48**				**2**
X2L	1.43	**0.48**	**0.48**				**2**
X1V	1.83	**0.48**	*(0.48)*		**450**	**25**	**3**
X1H	1.83	*(0.48)*	**0.48**		**450**	**25**	**3**

Total of 26 corrector magnets required (spares not included) – equivalent to 16 ‘nested’ packages

Potential increase of 4 dipole correctors (to reduce number of spool spares by one for net cost reduction) which shuffles the nesting

Corrector Magnet Overview

- Corrector requirements (field integrals) are similar to old correctors with the exception of the new strong quadrupole: 25T-m/m

Corrector type	Existing Correctors	C0 Requirements	units
dipole	.460	.480	T-m
quadrupole	7.5	7.5	T-m/m
Strong quadrupole	none	25	T-m/m
sextupole (up)	449	450	T-m/m^2
sextupole (down)	346	450	T-m/m^2
octupole	30690	none	T-m/m^3

- Detailed field quality specifications are under development

Limits on Corrector Harmonics
J. Johnstone

	X1, X2 Dipoles 0.48 T.m @ 1"		X1 Sextupole 0.145 T.m @ 1"		X3 Dipoles 0.48 T.m @ 1"		X3 Skew Quad 0.190 T.m @ 1"	
	[|bn|, |an|] **max** (units)	**Arch. Data**	[|bn|, |an|] **max** (units)	**Arch. Data**	[|bn|, |an|] **max** (units)	**Arch. Data**	[|bn|, |an|] **max** (units)	**Arch. Data**
b_0			**60**	**-20±145**			**10**	**109±208**
a_0			**60**	**-50±130**			**10**	**54±217**
b_1	**50**	**-3.1±3.8**	**50**	**-159±353**	**15**	**-3.1±3.8**	**60**	**-58±293**
a_1	**50**	**-2.2±34**	**50**	**52±379**	**15**	**-2.2±34**		
b_2	**100**	**-173±55**			**40**	**-173±55**		
a_2								

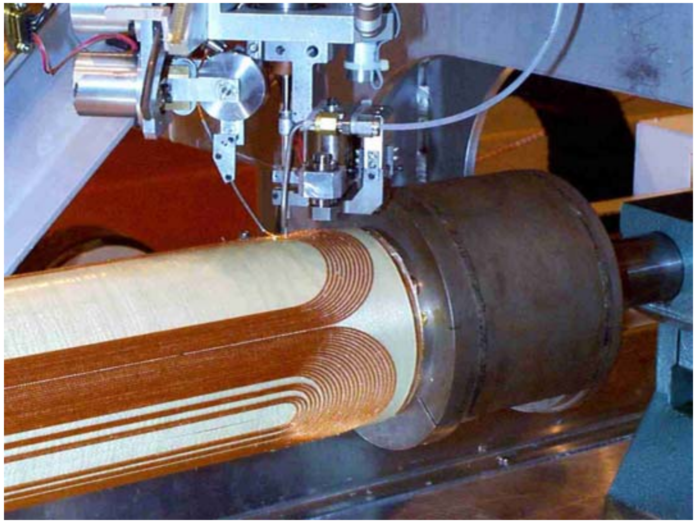
• Limits cause distortions of the 95% 20π beam envelope at the IP by ≤ 1 mm in βx① & βy① and/or ≤ 1μm in x① & y①
⇒ No noticeable hit on luminosity & no retuning of linear IR optics.

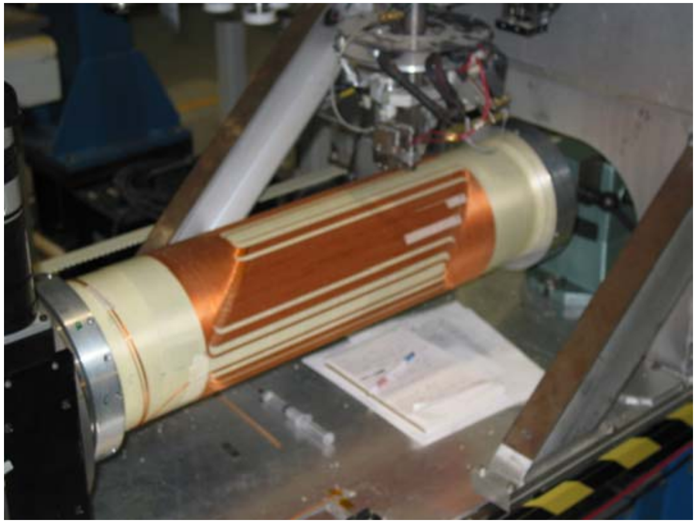
- Installed corrector power supplies are limited to 50A; this was an initial constraint imposed on the corrector design.
  - Magnet design studies indicate that a 100A limit allows greater flexibility (fewer turns/layers, lower inductance) in meeting field requirements.
  - Design constraint has been relaxed pending review of cost and performance tradeoffs.

- Approach to correctors
  - Review of existing corrector magnets indicated that none met our requirements (V. Kashikhin)
    - CERN LHC correctors
    - DESY HERA correctors
    - IHEP UNK correctors
    - Fermilab Tevatron correctors
      - Detailed analysis of archival data reveals surprisingly large field non-uniformities (mean and rms width) and strengths below design with large rms widths
  - TD developed conceptual designs
    - Determine field quality, transfer function, for assumptions on conductor parameters
    - Backup (risk reduction)

- Procurement Plan
  - Outside ‘vendor’ capable of design, fabrication, and testing to deliver corrector magnet packages ready for installation in spools
    - Removes potential conflicts with production and testing of high gradient quadrupoles – infrastructure and personnel
    - Removes potential conflicts with HTS leads testing and/or requirement for additional test dewar, electronics, and personnel
  - ‘First choice’ would be qualified LHC vendor or Laboratory with requisite expertise, personnel, and infrastructure
  - RFI sent to laboratories with recent corrector development experience
    - Brookhaven
      - RHIC correctors
      - DESY
      - Beijing
    - IHEP, Protvino
      - UNK
    - CAT, India
      - LHC
  - Continuing to pursue other vendor possibilities

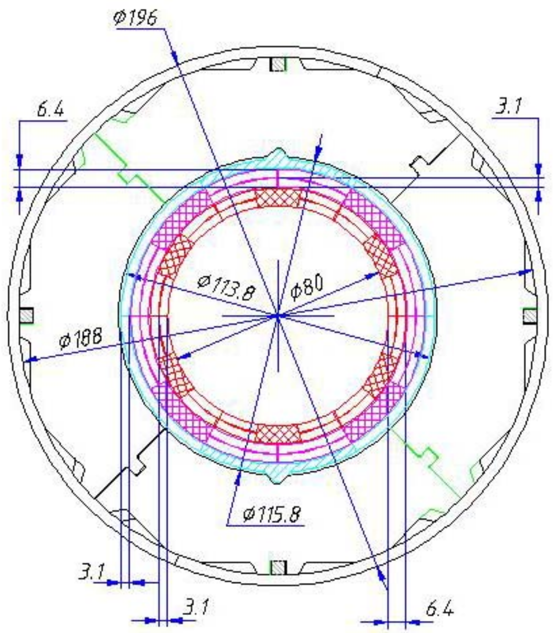
- BNL Coil Approach (from M. Anerella)
  - Direct wind (used for DESY & BEPC-II correctors)
  - Two configurations:
    - flat patterns – 'traditional' approach
    - "serpentine" – new approach which has intrinsic end cancellation





- IHEP, Protvino approach (from S. Kozub)
  - Ribbon-type cable made of 8 superconducting wires each 0.33 mm in diameter
  - Coils are shell-type, without wedges
  - Normal sextupoles and quadrupoles consist of two layers wound of one piece of cable, the other coils are single layer.

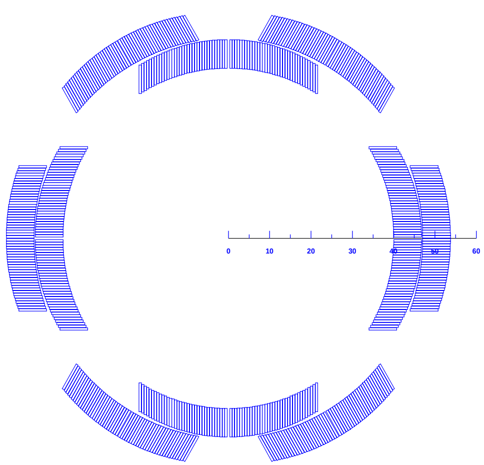
Corrector packages of X1V spool

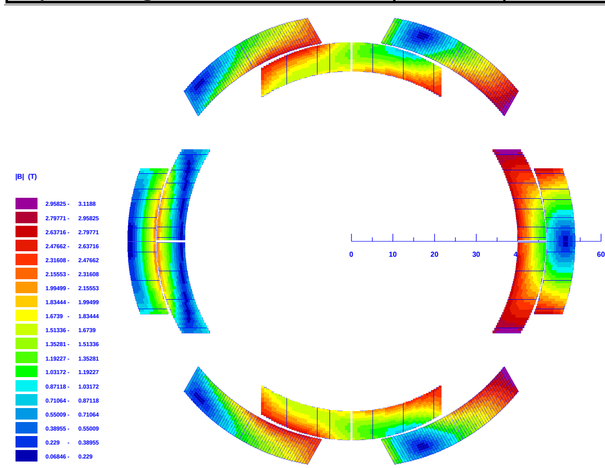


- Fermilab conceptual design (V. Kashikhin)
  - Single layer coils
  - G-10 wedge(s)
  - .5mm diam. wire
  - 100A current limit

Strong quad, normal sextupole configuration

Parameter	Unit	NQ	NS	ND
Field index n		1	2	0
Total cable turns		140	168	130
Coil IR	*mm*	40	47	40
Yoke IR	*mm*	58		51
Strands/cable		12		
Bare strand diameter	*mm*	0.5		
Cu/nonCu ratio		2		
J_{nonCu}(5T, 4.2K)	A/mm^2	2750		
Nominal strength	$T{\cdot}m/m^n$	25	450	0.48
Nominal current	*A*	100	93.5	100
Quench margin at nominal current in all the coils	%	41	43.1	47
Self inductance	*H/m*	0.949	0.979	2.121
Nominal stored energy	*kJ/m*	4.746	4.278	10.603
Magnetic length	*m*	0.6394	0.6396	0.2406
Physical length	*m*	0.76		0.44

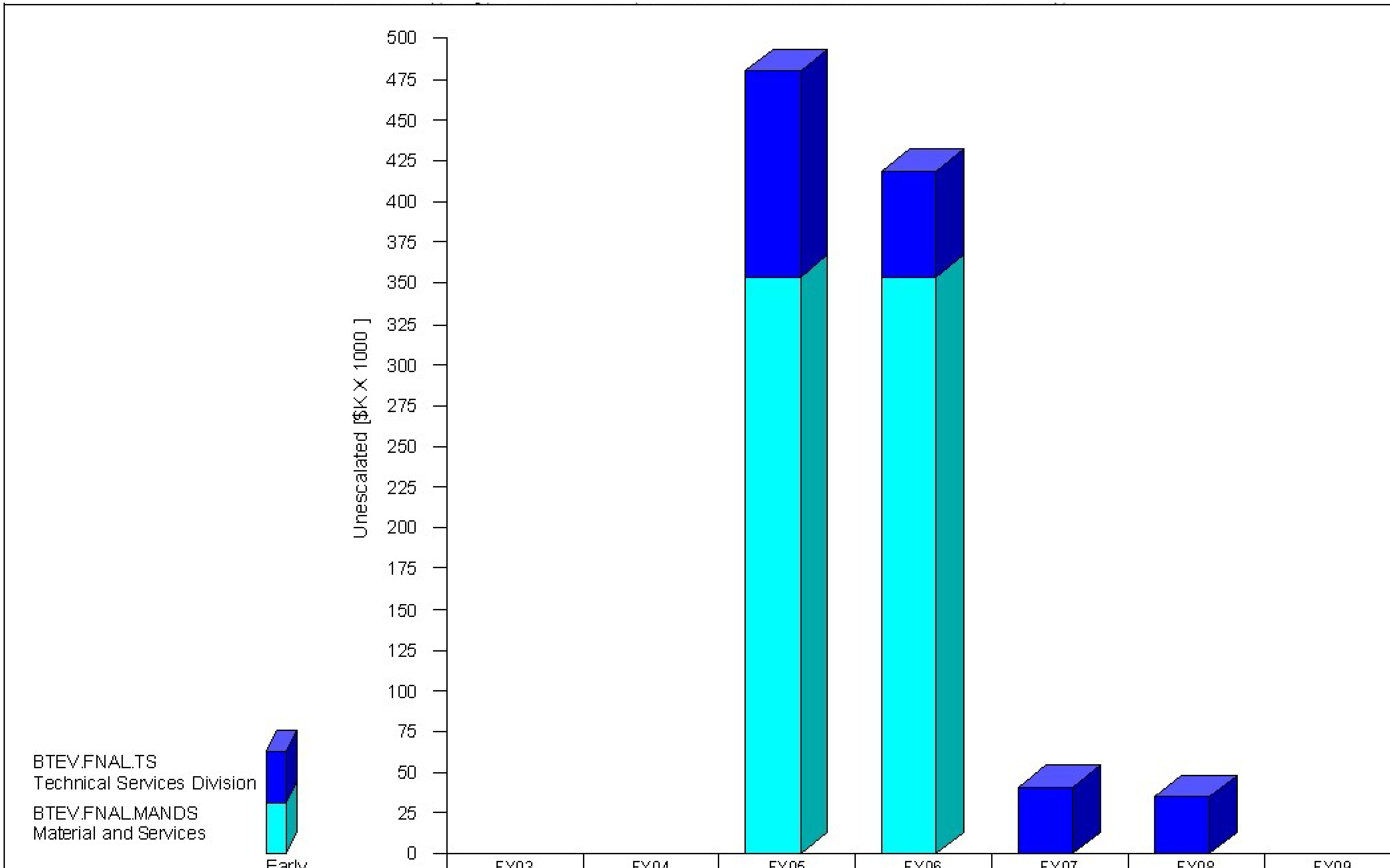




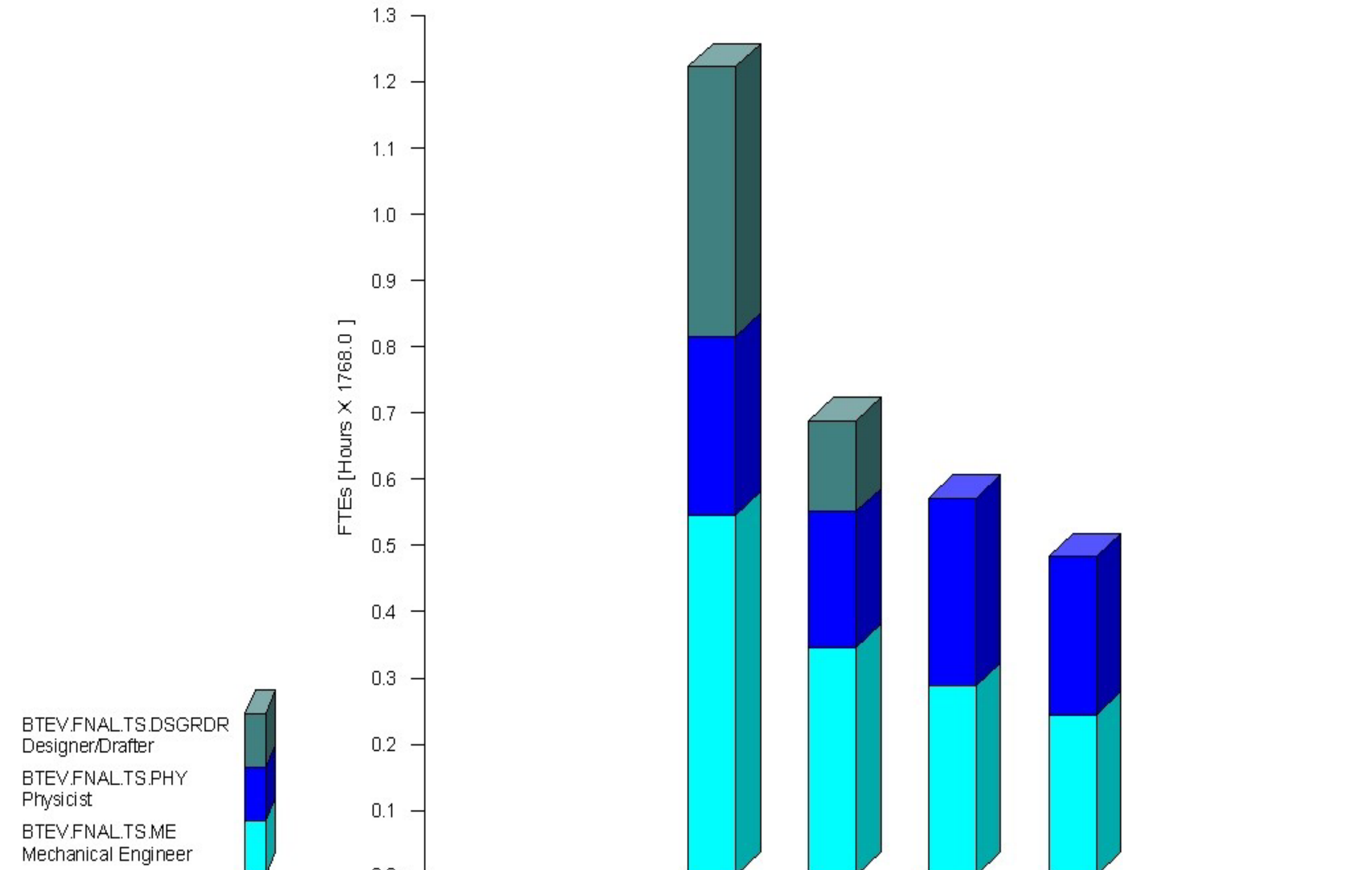
- Scope of work
  - Design of multiple correctors: dipole, quad, ‘strong’ quad, and sextupole including magnetic and mechanical structures
  - Major procurements are superconducting wire (‘ribbon cable’), magnet steel
  - Fabrication and testing of assemblies
  - Delivery to Fermilab for inspection and shipment to spool vendor
- Cost
  - Base cost: $974K (Procurement: $706K; Labor: $268K) does not include spares or contingency
  - Cost is based on CERN LHC corrector data

Total Cost Profile by Fiscal Year

WBS 2.1.2.2



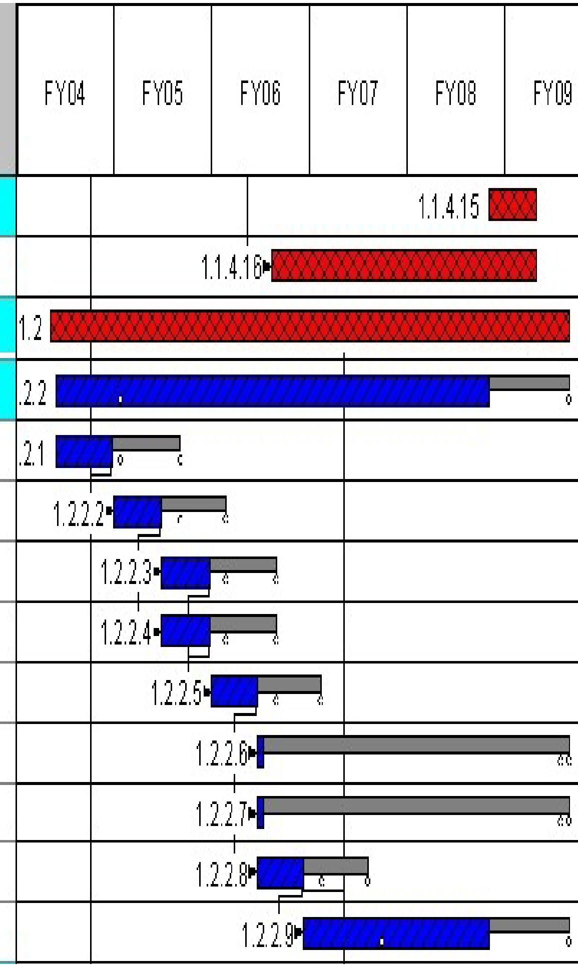
	Early	FY03	FY04	FY05	FY06	FY07	FY08	FY09
BTEV.FNAL.MANDS : Material and Services		0	0	353	353	0	0	0
BTEV.FNAL.TS : Technical Services Division		0	0	127	65	41	35	0



Early	FY03	FY04	FY05	FY06	FY07	FY08	FY09	FY10
BTEV.FNAL.TS.ME : Mechanical Engineer	0.0	0.0	0.5	0.3	0.3	0.2	0.0	0.0
BTEV.FNAL.TS.PHY : Physicist	0.0	0.0	0.3	0.2	0.3	0.2	0.0	0.0
BTEV.FNAL.TS.DSGRDR : Designer/Drafter	0.0	0.0	0.4	0.1	0.0	0.0	0.0	0.0

Plan and Schedule

Activity ID	Activity Description	Original Duration	Early Start	Early Finish
1.1.4.15	54-3	120d	04Aug08	28Jan09
1.1.4.16	Production Oversight in ICB	680d	**15May06**	**28Jan09**
1.2	New Spools	1347d	02Feb04	01Jun09
1.2.2	CORRECTOR MAGNETS	1122d	01Mar04	05Aug08
1.2.2.1	Corrector Magnet Design Selection	151d	**01Mar04**	**30Sep04**
1.2.2.2	Corrector Magnet Final Design and Detailing	120d	**01Oct04**	**28Mar05**
1.2.2.3	Bidding Process	131d	**29Mar05**	**30Sep05**
1.2.2.4	Bidding Process for spares	131d	**29Mar05**	**30Sep05**
1.2.2.5	Contract Evaluation	120d	**03Oct05**	**21Mar06**
1.2.2.6	Option to buy 2nd Batch	20d	**22Mar06**	**18Apr06**
1.2.2.7	Option to buy 2nd Batch of Spares	20d	**22Mar06**	**18Apr06**
1.2.2.8	Prototype Fabrication & Test	120d	**22Mar06**	**08Sep06**
1.2.2.9	Final Production Oversight	480d	**11Sep06**	**05Aug08**



Key Milestones

- RFP written – 29 Mar 2005
- Start of Production Correctors – 11 Sept. 2006
- Delivery of last corrector assembly – 5 Aug 2008

Critical Path Analysis

- Vendor selection
  - Agreement on design, cost, and schedule by end of Q2 FY2006
- Superconductor procurement
  - Wire/ribbon needed very soon after contract start
- Corrector Design
  - Preliminary design review
  - Final design review
- Tooling
  - Tooling design review
- Prototype fabrication and test
  - Production readiness review
  - Cold test of prototype

- Risks
  - Cost
  - Schedule
  - Vendor performance
- Mitigation
  - Multiple vendors contacted
    Specifications
    Contingency
  - Early start required
    Conductor order early
    Schedule monitoring
  - Oversight:
    Design Reviews
    Production Readiness Review

    "Plan B"- Build at Fermilab
    Continue corrector design
    Conceptual design of tooling
    (mods to existing tooling)

Summary

- We consider the technical risk to be reasonably low; the corrector designs proposed are conservative and use well understood techniques; the potential vendors contacted are experienced in this technology.
- Our approach to procurement is dictated by schedule and allocation of resources: we prefer to have a vendor take on the task of design, fabrication, and testing of the magnets. This has been done with success at CERN and elsewhere. ("Plan B" is for Fermilab to take on some portions or all of the task if necessary.)
- The cost estimate is still 'under construction' – it is based on CERN correctors costs but awaits more detailed cost estimates from our contacts with potential vendors.
- The schedule appears manageable – nearly two years for production – but is coupled to the spool assembly schedule. End dates for the entire project are critical so any slip in start dates (read: availability of funding) could present a problem.